led to a solution of this difficulty that has recently become rather common. It consists in arranging a circuit that actually takes advantage of the voltage drops in R_s and R_f to improve the general performance, so that capacitors C_f and C_{sg} are not only superfluous, but actually detrimental. The result is accomplished by adding a second tube and interstage coupling network to form a push-pull or balanced circuit. The important thing is that a single common resistor R_f is used for both cathodes connected together, and another common resistor R_s is used for the two paralleled screens. Capacitors C_f and C_{sg} are omitted entirely.

Briefly, an oversimplified description of the circuit action is as follows: The alternating components of the cathode currents of the two tubes are in phase opposition, and tend to cancel each other as far as the production of a-c potential drop in R_f is concerned. Exactly the same relations exist for the two screen currents, while correct direct-potential conditions are maintained by merely using resistors of half the size that would be used in the circuit of figure 1*a*. This arrangement has been criticized on the theory that it depends on balance and accurate matching of all elements on the two sides of the circuit; the tube elements being notoriously bad in this respect.

A thorough analysis of the push-pull circuit with common screen and cathode impedances under unbalanced conditions is quite lengthy and obviously cannot be given here. It is hoped that this may be made the subject of a separate paper in the near future. One result of the complete analysis pertinent to the present discussion is that the circuit works just about as well under severe unbalance as it does balanced. The reason is that the common cathode and screen resistors constitute a differential feedback circuit which always works in the direction to improve the balance. By proper circuit design this "balance forcing" action may be made very powerful, and results in an over-all response curve for the amplifier the same as curves 1 of figures 7 and 8 of the paper. The complete removal of phase shifts due to factors β and γ is a powerful advantage when stabilized feedback is attempted on the amplifier. In addition, a high-gain amplifier made of several stages displays a remarkable lack of sensitivity to common impedance and a-c ripple in the power supply.

Calculation and Design of Resistance-Coupled Amplifiers Using Pentode Tubes

Discussion and authors' closure of paper 40-52 by F. E. Terman, W. R. Hewlett, C. W. Palmer, and Wen-Yuan Pan, presented at the AIEE winter convention, New York, N. Y., January 22–26, 1940, and published in AIEE TRANSACTIONS, 1940, pages 879–84.

True McLean (Cornell University, Ithaca, N. Y.): This paper should be of considerable value to engineers charged with the duty of designing practical amplifiers, since it assembles for the first time almost all of the important factors involved in the particular type of circuit discussed.

Beginning with the well-known relation of equation 1 of the paper, first given by Hull and Williams in 1926, the authors add the three factors α, β, and γ of equation 2. The factor α is treated at length elsewhere by Doctor Terman, so the vital contribution of the paper is the rational derivations and uses of the factors β and γ. There appears to be no handy means of control over these factors that would tend to make them compensating, or reduce undesirable variations in α. The most desirable condition would therefore appear to be realized by making β and γ each equal to unity for all frequencies, This can be done in the circuit of figure 1 only by making the capacity of capacitors C_f and C_{sg} infinite. The practical difficulties are greatly aggravated if several stages are cascaded for the amplification of very small voltages. In this case a very small mutual impedance in the power supply will cause low-frequency oscillation (motorboating), and piling up capacitors on C_f and C_{sg} does not cure the trouble, but merely reduces the frequency of oscillation.

Several years ago (1931) the writer was

Frederick Emmons Terman: The use of push-pull circuits throughout an amplifier as advocated by Professor McLean is a very effective means of making the factors β and γ unity. Such arrangements are to be recommended where the amplification must be maintained down to very low frequencies.

At the same time it is to be kept in mind that in many cases one does not desire uniform amplification at very low frequencies but prefers some form of low-frequency cutoff. Under these conditions the screen-grid and bias impedances can be so proportioned as to aid in achieving the desired results as pointed out in our paper.